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Performance Analysis for the SRTM-Mission

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Abstract:

The Shuttle Radar Topography Mission (SRTM) flown on the Shuttle Endeavour from 11th to 22nd February 2000 has produced the most excellent interferometric image products ever obtained by a spaceborne SAR system. Its final product the global high precision digital elevation map will benefit numerous military and civilian applications.

The X-SAR mission operations team included four radar positions for instrument monitoring, performance analysis, contingency handling and radar data analysis. A key step in the acquisition of the high quality radar raw data was the performance analysis of the SAR system. The work presented here considers the major tasks for the *X-SAR Performance* position in the preparation and the carrying out of the SRTM mission. During the mission the *X-SAR Performance* position was operated in the *Payload Operations Control Center* (POCC) of the Johnson Space Center, Houston.

I. Introduction

The purpose of the X-SAR/SRTM Mission was to acquire data of the surface of the Earth [1]. Due to the fact that this radar system was no free-flying space system but operated inboard the Space Shuttle the data had to be collected on data recorders onboard the Shuttle itself. Strong NASA mass requirements permitted only a total amount of 120 tapes for X-Band data recording. Therefore the radar system could only be operated over land and had to be initialized at the beginning of each data take. For this reason the performance related parameters had to be calculated depending on the mission timeline provided by the dedicated Mission Timeline System (MPS). As a next step all timeline data has been processed by the PEWITS tool (Performance Estimator With Integrated Time System) and has been resent to the MPS where the radar parameter settings were stored in a data base. The base for this tool was a software performance analysis and prediction tool called PE (Performance Estimator), developed within DLR with the experimental experience of more than a decade [2]. The software has been extended to the specific and operational needs of the X-SAR interferometer.

During the X-SAR/SRTM flight the performance has been observed with a tool called 'Performance Analyzer' (PA). This tool allowed observing whether the pre-mission calculated parameter settings based on the mission timeline were sufficient regarding the required system performance.

II. The PEWITS Functionality

The PEWITS tool was designed to automate the process of setting SAR system parameters affecting the image quality with respect to the mission timeline. The mission timeline file included the information of land start and stop times, called 'data takes'. Figure 1 shows a typical data take over South America of the X-SAR/SRTM mission.

Figure 1: *DT of South America.*

Every data take consisted of at least four instrument commands: The first command has to set the radar system into transmit mode and to initialize the instrument parameters for the ocean calibration phase. The second command has to set the instrument parameters for data acquisition over land. The third command was provided for ocean calibration at the end of a data take, and the last command to set the radar instrument back to pause mode, marking the end of a data take. There could be more than those four commands depending on the Earth's surface which had to be mapped. Especially for large variations in the

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terrain height the data window had to be set to dedicated positions. For significant changes of the backscatter behavior the receiver gain settings had to be set to appropriate values when the radar was not operated in 'Automatic Gain Control (AGC)' mode.

The timeline information has been processed within the PEWITS tool by calculating and setting the performance related parameters for every necessary command. Figure 2 depicts the GUI of PEWITS and shows an example of command events in chronological order.

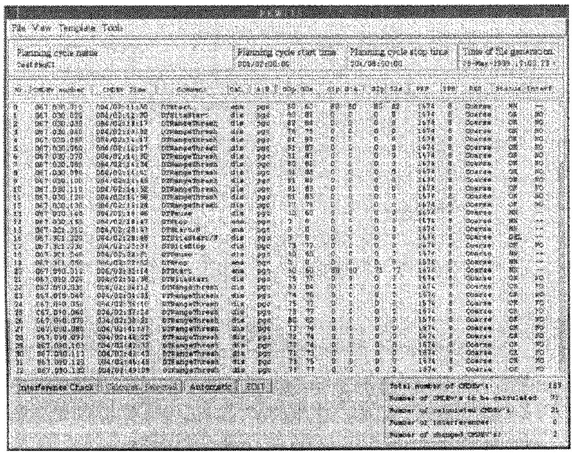

Figure 2: *PEWITS GUI.*

Furthermore the operator of the software could check if parameters like the PRF would cause transmit pulse interference. Therefore the possibility existed to edit the timeline commands for performance reasons. Another parameter of interest was the Data Window Dwell Time (DWDT) and the Data Window Dwell Direction (DWD). These two parameters were responsible for shifting of the Data Window Position (DWP). After a certain amount of seconds, given by the DWDT, the DWP should move one discrete step à 9.965 μs towards or against the corresponding transmit pulse (direction given by DWD). Thus the two requirements to adapt the DWP to the Earth's surface (including terrain height model) and to use as few commands as possible were met. A further task of PEWITS consisted of checking if the DWDT and DWD for both channels were set correctly.

III. The Performance Analyzer Functionality

Calculation of radar parameter settings was done every 12 hours before the settings were sent to the radar system located in the payload-bay of the Space Shuttle. Monitoring of the current radar settings was the other main task the position *X-Performance* was responsible for. This was done by visualizing the telemetry which was received from the Space Shuttle via S-band downlink. Those values had to be compared with the planned data. Also the data quality had to be assessed by the operator. This was done by assessing the Analog-Digital Converter (ADC) overflow rates, the data window positions, and the echo profiles of the inboard and outboard radar system. Figure 3 shows the graphical user interface of the PA software and Figure 4 an example of the the outboard channel settings in detail.

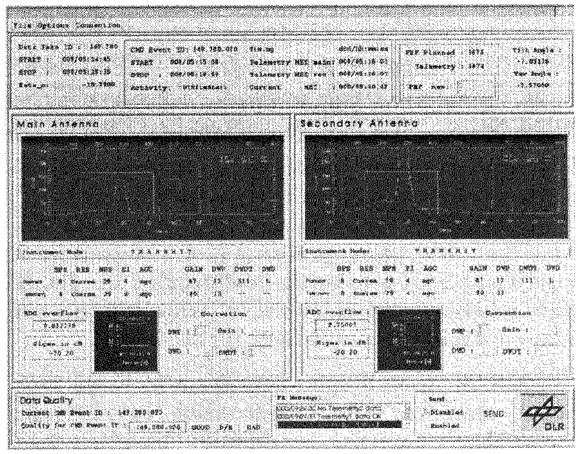

Figure 3: *Performance Analyzer GUI.*

In the lower right corner it is indicated that the operator had the possibility to change parameters during the execution of the commands of the current data take. For each channel the DWP, the DWDT, the DWD and the gain setting could be modified.

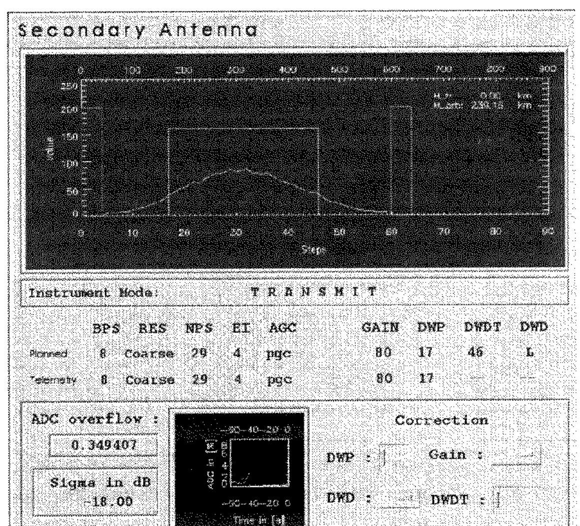

Figure 4: *Outboard Channel Settings.*

This process could be done by sending a so-called 'near-real-time command' to the X-SAR/SRTM Command System (CS) ('near'-real-time because the command uplink to the Shuttle was shared between the two different radar systems). The operator was also able to monitor the tilt angle of the inboard X-SAR antenna and the latitude of the calculated DT. This would help the operator to interpret changes of the DWP due to different look angles or wrong latitude values.

IV. Assessment of Interferometric Performance

A fundamental step in the development and optimization of a SAR system is usually performed by an analytical assessment of image quality parameters like e.g. spatial and radiometric resolution, signal-to-noise ratio and ambiguity ratios. For the X-SAR/SRTM mission a special focus had to be directed of course to the interferometric performance. Two important parameters defining this performance are the relative height error and the absolute height error in the digital elevation model. The typical performance calculation is an iterative optimization process, which is depicted simplified in Figure 5.

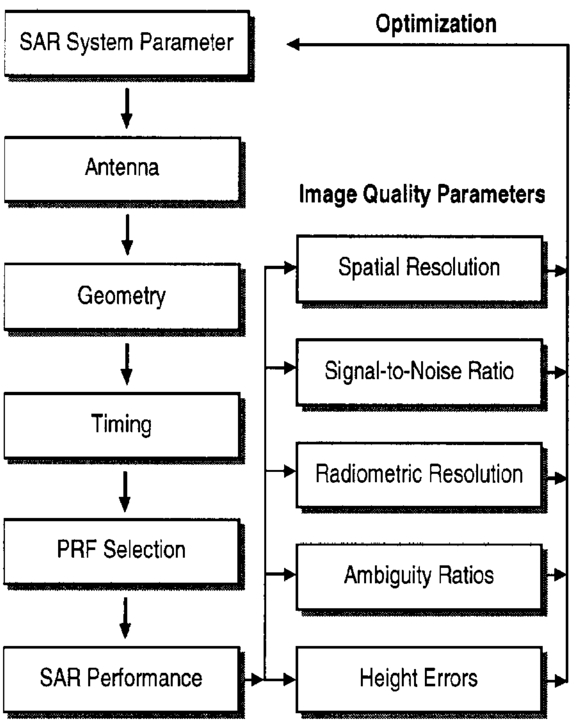

Figure 5: *Approach of Performance Analysis.*

One of the most important steps in the design process is the selection of the pulse repetition frequency (PRF), which is a highly restricted parameter. Once the PRF is determined the image quality parameters can be evaluated in an analytical way. By assessment of these quality parameters the SAR system parameters can be optimized.

V. System Parameters of the X-SAR Instrument of SRTM

In the beginning of the system parameter planning for the X-SAR system of SRTM the overall orbit constellations were developed. To cover the whole landmass between +60 deg and –57 deg latitude within 11 days an orbit height ranging from 233 km to 249 km was necessary for the C-band Scan SAR system [3]. The variation of the effective height over ground was due to the trim burn maneuvers of the Space Shuttle and the deviations of the Earth's surface.

Due to the historical development from SRL 1/2 [1] the X-SAR system has the ability to operate just eleven different PRF modes ranging from 1240 up to 1736 Hz. The problem was to find a PRF that could be kept constant for the whole range of orbit heights. A change of the PRF during data takes was not acceptable for the interferometric processing. Additionally the swath width and image quality should be optimized. Figure 7 and Figure 6 illustrate the unacceptable PRF bands for the minimum and maximum orbit height. To perform a data take with a constant PRF, the data window area must remain within the pulse repetition interval for both constellations.

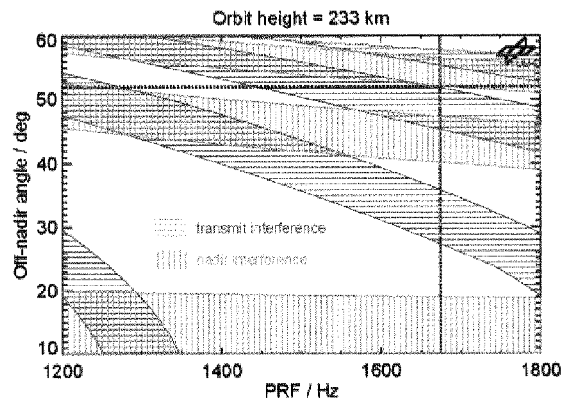

Figure 7: *PRF restrictions at 233 km orbit height.*

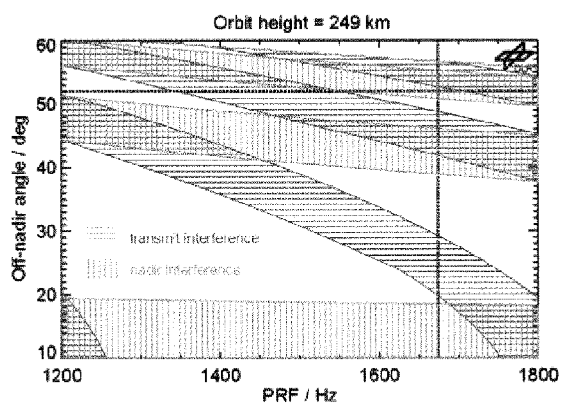

Figure 6: *PRF restrictions at 249 km orbit height.*

Further restrictions to the off-nadir angle resulted from the integration of the X-SAR main antenna next to the C-band radar antenna and the AODA system (Attitude and Orbit Determination Avionics) [4]. This configuration required a minimum off-nadir angle of

51 deg for the X-SAR main antenna. From Figure 7 and Figure 6 it can be seen, that combinations of PRFs with off-nadir angles above 51 deg, avoiding both transmit and nadir inter-ferences, are possible just for PRFs less than 1350 Hz. PRFs in that order result in a poor azimuth ambiguity suppression in the secondary channel since the X-SAR outboard antenna has just half the length of the main antenna.

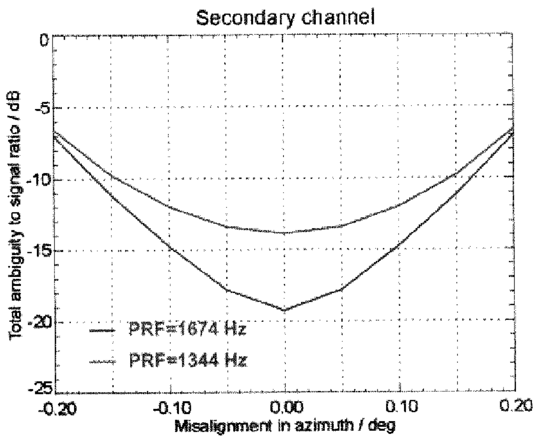

Figure 8: *Ambiguity ratios of the secondary channel.*

Figure 8 illustrates the difference in ambiguity suppression for the PRFs 1674 Hz and 1344 Hz in the secondary channel. The total ambiguity ratio is mainly driven by the azimuth ambiguity ratio. A misalignment of both antennas yields further degradations. Fortunately the accuracy and stability of the alignment experienced throughout the mission was less than 0.025 deg and better than expected [4]. The ambiguity ratios in both channels affect the overall height resolution of the interferometer. The estimated relative and absolute height errors are shown in Figure 9 for both PRFs. The degradation of height resolution at the low PRF is mainly given by the poor azimuth ambiguity suppression. For a perfect alignment the estimated relative height error is 6.4 m worst case, i.e. at the far range of the swath for the PRF 1674 Hz and 7.36 m for the PRF 1344 Hz. At near range the relative height error is expected to be about 5.2 m for the PRF 1674 Hz.

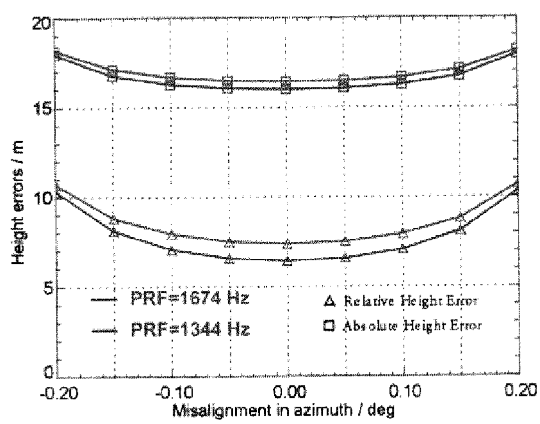

Figure 9: *Relative and absolute height errors.*

This shows clearly that the high PRF is more favorable for the interferometric performance. The remaining problem was the nadir interference. As depicted in Figure 10 the elevation patterns of the X-SAR antennas have a Tschebyscheff tapering yielding very low side lobes between 31 and 55 degrees off-nadir.

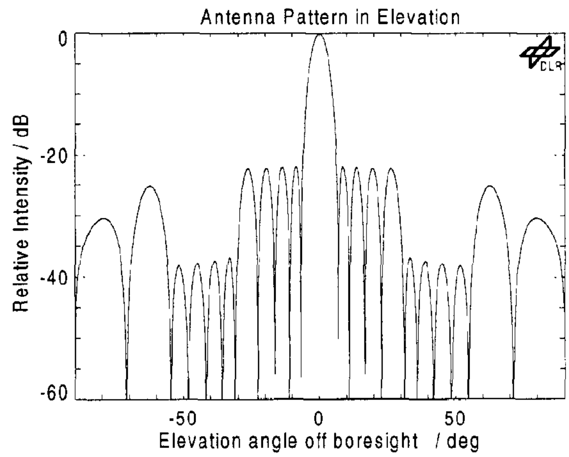

Figure 10: *X-SAR antenna pattern in elevation.*

This revealed the freedom to accept nadir interferences and to improve azimuth ambiguity suppression and hence height resolution significantly. The best possible choice turned out to be the PRF of 1674 Hz at a look angle of 52 deg. The preliminary radar data analysis during the mission confirmed that nadir echoes appeared noticeable just in few cases [5]. The detailed analyses of the first SRTM image products indicate that the average height resolution is in very good correspondence with the predicted values in Figure 9. The average height resolution may even exceed the estimated values.

VI. Mission Experience

The key system parameters were determined during the design phase of the project. The most important remaining parameters which have been calculated during the operating phase were:

a) Receiver gain settings for both radar channels depending on the backscatter coefficient of the Earth's surface.

b) Data window positions for both radar channels with respect to the terrain height (a rough model was used).

As a first result from post-mission processing of the radar data the signal standard deviation was about 35% below the maximum ADC amplitude [6]. This is close to the optimal value of 30% giving the best compromise between clipping and reduction of ADC quantisation noise. The gain settings for both radar receivers were optimally estimated by the Performance Estimator software but the maximum gain of both channels was limited to 80 dB. The receiver gain setting variation of the primary channel was between 74 and 80 dB, mostly at the maximum setting. The stronger secondary channel had a range of gains between 70 and 80 dB.

The only critical contingency that occurred during the SRTM mission was the failure of a thruster at the outboard antenna to compensate the Earth's gravitational forces on the mast. During the contingency handling different options were discussed. One option was to change the roll angle of the whole Shuttle to reduce these forces. A change of the roll angle would also have changed the look angle of the SAR system. In this situation it was vital to have a software tool like the Performance Estimator to find suitable system parameters for these hypothetical configurations in a very short period of time. These analyses were similar to the ones presented in chapter 5. The results were the basis for further decisions in the contingency management.

VII. Summary

In this paper, the software tools which were utilized for the performance estimation of the X-SAR interferometer in the preparation and the carrying out of the SRTM mission were presented. The functionality and the versatility of the software were demonstrated. The analyses of the first SRTM digital elevation models indicate that the average height resolution is as good as predicted or even better. A final comparison can be done after all data takes are processed.

VIII. References

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